Technological complex for utilization of high-calcium ash and slag for Abakan thermal power plant

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Abstract
The Siberian State Academy for Mining and Metallurgy (SSAMM) and Uglestrinproject have developed a project for complex utilization of waste produced by burning brown coals from Kansk-Achinsk Power Complex at the Abakan thermal power plant. The project provides for total utilization of ashes and slags from the thermal power plant for producing finished 'cementless' binder and aggregate, finished 'cementless' fine ash/slag concrete and mortar, precast reinforced concrete structures and small products (silicate brick). Previous investigation of ash and slag from the thermal power plant and concretes on their base was completed in 1995. After grinding and introducing silica time, ash and slag to meet the requirements of State Standard 25818-91, concrete is in accordance with State Standard 26633-91.

The technological complex providing loo-percent utilization of waste products from the TPP includes departments for grinding ash with a storage, for producing sand from slag with a storage, molding with concrete mixers and premises for admixtures. The project has been approved by a nature committee of the Khakass Republic and is in accordance with the ecological standards. The construction of the complex is currently under way.
Keywords: High-calcium fly ash, slag sand, silica fume, cementless binder, technological complex.

1 Introduction

One of the trends towards the utilization of fly ash and slag waste products from thermal power plants, particularly those using brown coals, is the production of construction materials, mortars and concretes for various practical uses.

This work presents the results of a study and a project for a complex utilization of ash and slag from the Abakan thermal power plant, located in the Khakass republic, which is burning brown coals from the Kansk-Achinsk Power Complex. The project provides for the utilization of the total volume of high-calcium ashes and slags from thermal power plants for producing the following materials: finished binder and fine aggregate in the form of slag sand with the particle size of 0 to 5 mm, marketable cementless and lean mortar and concrete as well as precast structures and small concrete products.

Profitability of the project has been achieved through the use of cheap initial materials for the production of the above products.

2 Properties of materials used

2.1 Fly ash

The fly ash from the Abakan thermal power plant was investigated in accordance with two standard documentations:

1. Specification 34-70 10898-88 [1] developed by SibZNIIEP, IKhTTIMS of the Siberian Branch of the Academy of Sciences of the USSR NIIZhB Gosstroy USSR and Moscow Institute of Steel and Alloys;
2. State Standard 25818-91 [2] developed by the leading institutions of Russia with the participation of the first authors.

According to the requirements, physical properties of the ash from Kansk-Achinsk Power Complex were standardized by its fineness and residue on sieve № 008. The data obtained by the authors were compared with the data obtained by SibZNIIEP (Novosibirsk) who investigated ashes from the Kansk-Achinsk Power Complex coals burned at the Novosibirsk power plant and Barnaul thermal power plant №3 [3]. The physical properties determined in accordance with State Standards 3 10.2 - 76 and 3 10.3 - 76 [4,5] are given in Table 1.

Table 1 - Physical Properties of Ash from Abakan Power Plant

Properties	Standards			SibZNIIEP data, Ash from Novosibirsk TPP	SSAMM data, Ash from Abakan TPP
	Specification 34-70.10898		State Standard 25818-91		
	First Grade	Second Grade			
Surface area, no less than, cm^2/g	2800	2000	2500	2996	2358
Residue on sieve №008, no more than,	12.00	15.00	20.00	10.27	7.50

As can be observed from the data given in Table 1, the ash from Abakan thermal power plant can be referred to as a second grade ash due to its fineness, and as a first grade ash due to the residue on the sieve. It exhibited worse properties than the ash from the Novosibirsk power plant №3. For improving its characteristics, raising its chemical activity and eliminating irregular spreading, the ash needs grinding.

Chemical analysis of the ash for oxide and unburnt particles contents made in accordance with State Standard 5382-91 is given in Table 2. The results of the ash analysis can be summarized as follows.

Table 2 - Chemical Analvsis of Ash from Abakan Power Plant

Oxides	Standards			Ash from Novosibirsk Power Plant	Ash from Abakan Power Plant
	Specification 34-70.10898		State Standard 25818-91		
	First Grade	Second Grade			
SiO_2				20.93	39.45
incl. free SiO_2				16.87	24.20
Total CaO		-		31.95	31.20
incl. free CaO	6.00	9.00	5.00	5.51	8.91
MgO	3.00	7.00	5.00	5.96	6.31
Al_2O_3				7.64	7.11
$FeO+Fe_2O_3$				15.37	10.79
MnO				0.44	0.18
P_2O_5		-		0.23	0.06
SO_3	5.00	5.00	3.00	1.87	0.86
TiO_2				0.76	0.90
Na_2O+K_2O	-		1.50	1.80	1.10
Loss on ignition	3.00	5.00	3.00	3.45	1.85
Coefficient of quality, $c_q = \frac{CaO+Al_2O_3+MgO}{SiO_2}$ no less than	1.20	1.00	-	1.47	1.13

1. The coefficient of quality for determining binding properties of the ash [3] indicated that the binding properties of the ash from the Abakan power plant were less (more than 1 .O but less than 1.2) than those of the ash from the Novosibirsk power plant (1.3 times higher).

$$C_q = (31.20 + 7.11 + 6.317)/39.45 = 44.62 / 39.45 = 1.13$$

2. Due to calcium oxide (8.91%) and magnesium (6.31%) contents, the ash was referred to as the second grade.
3. Due to the contents of sulfate compounds and loss on ignition (0.86 and 1.85, respectively), the ash was referred to as the first grade.

Though the values of the first two indices were low, the ash had a potential activity reserve. A high percentage of the free silica content of the ash increased its binding properties after its grinding, subsequent treatment with water and heating. Magnesium-containing minerals were also activated after grinding. The data on the SO_3 content and loss on ignition were encouraging in terms of durability of the future concrete and protection of reinforcement from corrosion.

2.2 Granulated slag

The slag from the Abakan thermal power plant was studied in accordance with the requirements of State Standard 26644-U [6]. The glassy slag was separated into two grading fractions: 5 to 10 mm slag rubble (7.5%) and 0.14 to 5 mm slag sand (92.5%). While assessing the slag sand, the characteristics to be considered were bulk density, granulometric composition and chemical analysis. The bulk density determined in compliance with State Standard 9758-86 [7] was 1.58 g/cm^3 (1580kg/m^3).

Grain composition of the slag sand determined in accordance with State Standard 873 5-88 [8] is given in Table 3.

Table 3 - Grading of Slag from Abakan Thermal Power Plant

Sieve size, mm	Residue on Sieve	Cumulative percentage retained, %
5.000	75.0g 75.0%	75.0
2.500	56.2g 56.5%	64.0
1.200	21.5g 21.5%	85.5
0.630	55.0g 5.0%	91.0
0.3 15	50.0g 5.0%	96.0
0.140	30.0g 3.0%	99.0
< 0.140	10.09; 1.0%	100.0

The data on the grain composition indicated that the cumulative percentage retained on the sieve № 063 was 9 1% which was above normal (65%) while the fineness modulus was 4.3 5 which did not meet the requirements of fine aggregates for concrete (2.5 to 3.1 for denser packing). However, grading fraction of 5 to 10 mm revealed microcracks. Therefore, all the slag needed grinding to 0 to 5 mm particle size so it could be used in fine ash-slag concrete containing no natural aggregates. The absolute density of the slag sand was 2150 kg/m^3.

Frost resistance was determined is accordance with State Standard 9758-86 [7]. Before grinding, the frost resistance of slag was equal to 102 cycles of freezing and thawing, whilst after grinding to a particle size of 0 to5 mm, the frost resistance increased to 235 cycles versus 200 cycles according to a State Standard for a dense slag.

Testing for oxide contents was performed in accordance with State Standard 25589-83 [9,10]. The chemical analysis is given in Table 4. The data given in Table 4, showed that the slag sand meets the requirements of State Standards for use in concretes. Resistance of the slag to silicate and ferric decomposition was determined in compliance with State Standard 9758-86 [7]. The weight losses were 6.38 to 6.70% (up to 8% according to State Standard) and 4.42 to 4.60% (up to 5% according to State Standard) for silicate and ferric decomposition, respectively.

Table 4 - Chemical Analvsis of Slag from Abakan Thermal Power Plant

Oxides	Quantities, %	
	State Standard	Actual Sample
Total SiO_2	no standard	56.47
Free SiO_2	no standard	15.51
Total CaO	no standard	29.92
Free CaO	no more than 1%	
Al_2O_3	no standard	8.16
Fe0	no standard	8.20
Fe_2O_3	no standard	1.43
MgO	no standard	3.50
MnO	no standard	0.17
P_2O_5	no standard	0.05
SO_3	no more than 3%	0.11
Loss on ignition		
for dense slags	no standard	
for porous slags	no more than 3%	

2.3 **Silica fume**

Silica fume from the Kuznetsk ferroalloy plant was a fine powder (5 to 6 times finer than cement) of a light grey colour with a fineness of 2200 to 3000 m^2/kg. The data on test results are given in Table 5. X-ray diffraction and DTA showed the presence of silicon oxide mostly in the amorphous from, which increased the hydraulic activity of the silica fume while reacting with lime and binding free lime of a high-calcium ash. The hydraulic activity was assessed by determining the amount of lime absorbed by silica fume from a saturated solution at 85°C. It was 102 mg CaO/g.

Table 5 - Physical Properties and Chemical Analysis of Silica Fume

Physical Test	Results
Fineness -passing 45 mm, % – Blaine, m^2/kg Specific Gravity Colour	 100 2900 2.25 light grey
Chemical Analysis, %	
SiO_2 total, including	90.11
SiO_2 free	82.00
CaO total	0.71
MgO	0.97
Al_2O_3	1.93
$FeO+Fe_2O_3$	1.82
MnO	0.20
P_2O_5	1.18
Na_2O+K_2O	2.03
Loss on ignition	2.05

3 Optimum mixture proportions

Optimum mixture proportioning of an ash-slag-silica fume blend was obtained on the basis of previous studies [11, 12, 13] and new experiments using a mathematical method of planning [14]. Testing of structures and products (silicate brick in this case) were also made. The test results meet the requirements of up-to-date State Standards for concretes and silicate brick. The optimum mixture proportions for the ash-slag-silica fume blend were the following:

High-Calcium fly ash - 650 - 750 kg/m^3
Silica fume - 70 - 80 kg/m^3
Slag sand - 1000 - 1100 kg/m^3
Water - 180 - 210 kg/m^3
Superplasticizer - 0.7 - 2.0 kg/m^3 (0.1 - 0.3 % by weight of a binder)

As a result of the investigation and tests performed, non-autoclave ash-slag-silica fume brick has been produced with a compressive strength of 12.5 to 15 .0 MPa, frost resistance of 50 to 75 cycles and an average density of 1900 to 1950 kg/m^3 which meets the requirements of State Standard 379-89 “Silicate brick. Specification”.

4 Technological scheme for utilization of ash and slag from Abakan thermal power plant

A technological scheme for processing ash and slag and a project of a technological complex for the Abakan thermal power plant have been developed. Collected by electrostatic filters, the high- calcium fly ash with a fineness of 2400 cm^2/g was ground in ball and tube mills to a fineness of 4000 cm^2/g in order to destroy agglomerated particles and fused surface of the ash and thus increase its hydraulic activity. Besides, the grinding stimulated interaction between free calcium oxide and the amorphous microsilica.

Slag from the thermal power plant in a melted state was granulated and then ground by roller crushers to a particle size of 0 to 5 mm. This procedure improved the granulometric composition of the aggregate, eliminated microcracks and stresses in the slag, improved its frost resistance and hence, the properties of the future concretes.

20 to 30 percent of the processed ash and slag is sold to builders while 70 to 80 percent is used for producing various types of concrete and products as well as used in concrete for reconstruction and expansion of the thermal power plant. The schematic diagram of the complex for utilization of fly ash and slag from the thermal power plant is given in Figure 1.

An ash-slag-silica fume blend was made in mixing-crushing runners or fixed-drum concrete mixers using hot water (60-80°C) at 12% relative humidity of the mixture. Brick was produced by dry pressing at 20 to 25 MPa and then was moist-cured in a steam-curing chamber at 95 to 100°C using a 3+10+3 h cycle. The use of 0.1 to 0.3% high-molecular S-3 superplasticizer greatly improved workability of the mixture and increased the strength and durability of the brick. With free CaO contents ranging from 5 to 15 percent the strength characteristics of the ash-slag-silica fume brick did not change greatly.

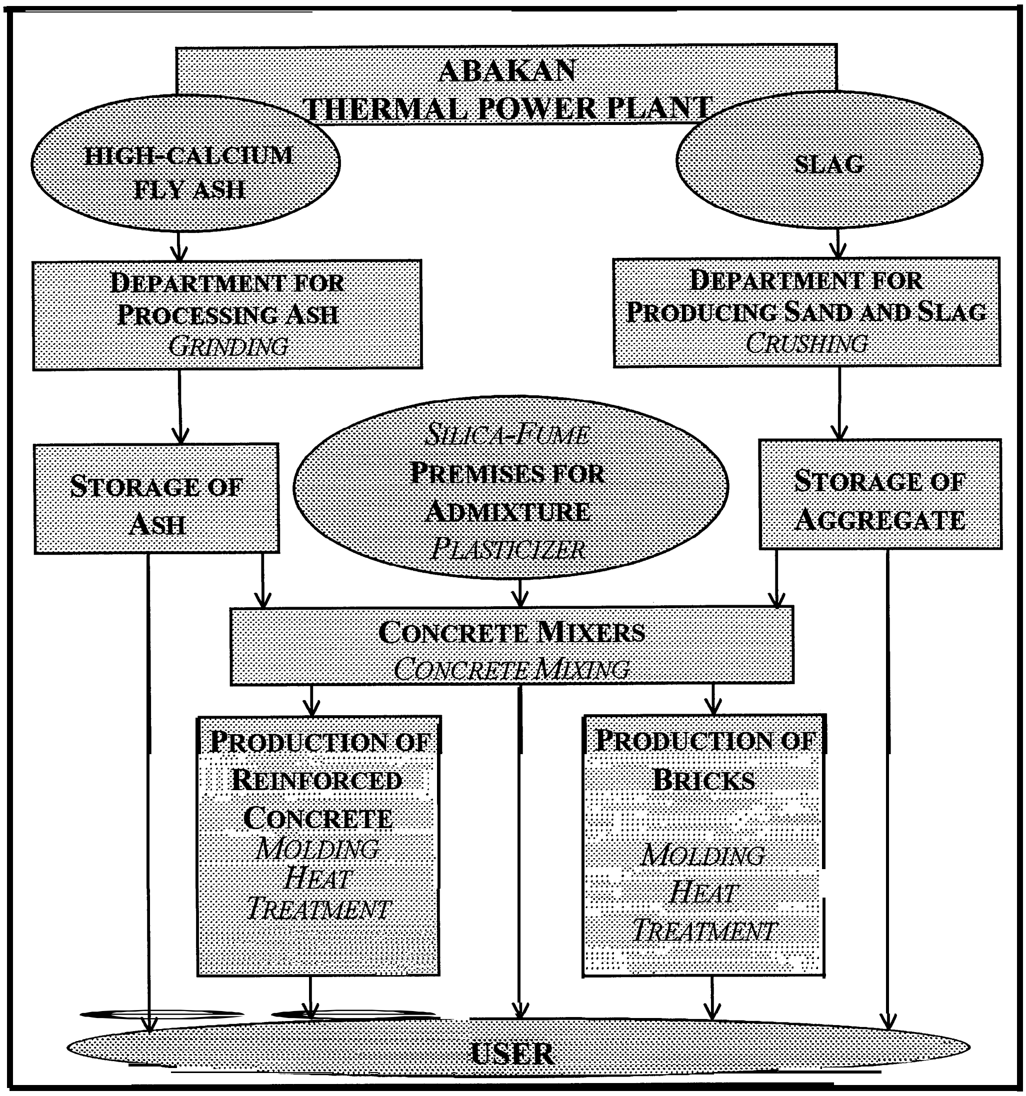

Figure 1 - Schematic diagram of total utilization ash and slag from thermal power plant

5 Technological complex for utilization of waste from power plants

The technological complex provides for the 100 percent utilization of wastes from the Abakan thermal power plant and includes the following facilities:
-the department for grinding ash with a store;
-the molding department with mixers, one of which is designed for the production of a ready-mixed concrete;
-the storage for finished products;
-the storage for admixtures, fuels and lubricants;
-the department for the production of sand from slag with a store for finished products.

6 Conclusions

1. The technology and a “Technological Complex for Utilization of Waste from Power Plants” project for producing ready-mixed concrete, reinforced-concrete structures and ash-slag-silica fume brick have been developed.

2. Organization of the production of ground ash, slag sand, structures and brick at the Abakan thermal power plant permitted the solution of the problem for the total utilization of wastes using steam and energy of the plant which reduced the cost of the products made of the wastes.
3. The cost of the production of a 'cementless' ready-mixed concrete and the ash-slag-silica fume brick are 60 and 65 to 70 % lower-than the production of a cement concrete and silicate brick hardened in an autoclave, respectively.

7 References

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